Comment on "Five-Body Cluster Structure of the Double-Λ Hypernucleus ${}^{11}_{\Lambda\Lambda}$Be"

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Hiyama *et al.* [1] have recently reported on a pioneering five-body $\alpha\alpha n\Lambda\Lambda$ cluster-model (CM) calculation of ${}^{11}_{\Lambda\Lambda}$Be in order to confront a possible interpretation of the KEK-E373 HIDA event [2]. Unfortunately, a six-body $\alpha\alpha nn\Lambda\Lambda$ calculation of ${}^{12}_{\Lambda\Lambda}$Be to confront another possible interpretation is beyond reach at present. Using experimental B_Λ values with small corrections based on recently determined ΛN spin-dependent interaction parameters [3], we obtain binding-energy shell-model (SM) estimates for both ${}^{11,12}_{\Lambda\Lambda}$Be, concluding that neither ${}^{11}_{\Lambda\Lambda}$Be nor ${}^{12}_{\Lambda\Lambda}$Be provide satisfactory interpretation of the HIDA event. The SM approach is tested by reproducing $B^{\rm exp}_{\Lambda\Lambda}({}^{13}_{\Lambda\Lambda}{\rm B})$.

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The input to the SM estimates consists of three Λ-spin-dependent ΛN interaction parameters (Δ, S_Λ, T) fitted to the six known Λ hypernuclear doublet splittings beyond ${}^{9}_{\Lambda}$Be and of the induced nuclear spin-orbit parameter S_N extracted from the excitation energy of ${}^{16}_{\Lambda}{\rm O}(1^-_2)$. The fit also includes a $\Lambda-\Sigma$ coupling interaction [3]. For this fit, with a spin-independent ΛN interaction parameter $\overline{V}_{\Lambda N} = -1.04$ MeV, ground-state (g.s.) binding energies of Λ hypernuclei with mass number $A = 10, 11, 12$ are reproduced to within $\delta B^{\rm SM}_\Lambda \lesssim 0.2$ MeV. The associated SM estimate for the $\Lambda\Lambda$ binding energy of the $\Lambda\Lambda$ hypernucleus ${}^{\rm A}_{\Lambda\Lambda}$Z is given by

$$B^{\rm SM}_{\Lambda\Lambda}({}^{\rm A}_{\Lambda\Lambda}{\rm Z}) = 2\overline{B}^{\rm SM}_{\Lambda}({}^{\rm A-1}_{\ \ \Lambda}{\rm Z}) + \langle V_{\Lambda\Lambda}\rangle_{\rm SM}, \qquad (1)$$

where $\overline{B}^{\rm SM}_{\Lambda}({}^{\rm A-1}_{\ \ \Lambda}{\rm Z})$ is the $(2J+1)$-averaged binding energy of the g.s. doublet in the Λ hypernucleus ${}^{\rm A-1}_{\ \ \Lambda}{\rm Z}$, as appropriate to the spin zero $(1s_\Lambda)^2$ configuration of ${}^{\rm A}_{\Lambda\Lambda}$Z. The $\Lambda\Lambda$ interaction contribution to $B_{\Lambda\Lambda}({}^{\rm A}_{\Lambda\Lambda}{\rm Z})$ is deduced from the NAGARA event [2]: $\langle V_{\Lambda\Lambda}\rangle_{\rm SM} = B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}{\rm He}) - 2B_\Lambda({}^{5}_{\Lambda}{\rm He}) = (0.67 \pm 0.17)$ MeV, close to $\langle V^{\rm CM}_{\Lambda\Lambda}\rangle = B_{\Lambda\Lambda}(V^{\rm CM}_{\Lambda\Lambda}) - B_{\Lambda\Lambda}(V_{\Lambda\Lambda} = 0) \approx 0.55$ MeV, with $V^{\rm CM}_{\Lambda\Lambda}$ also fitted to $B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}{\rm He})$ [1]. Table I lists $\overline{B}^{\rm SM}_{\Lambda}({}^{\rm A-1}_{\ \ \Lambda}{\rm Z})$ input to Eq. (1), constrained by $B^{\rm exp}_{\Lambda}({}^{\rm A-1}_{\ \ \Lambda}{\rm Z})$ values [4], plus $B^{\rm SM}_{\Lambda\Lambda}({}^{\rm A}_{\Lambda\Lambda}{\rm Z})$ predictions.

TABLE I: SM input and $B^{\rm SM}_{\Lambda\Lambda}({}^{\rm A}_{\Lambda\Lambda}{\rm Z})$ predictions (in MeV).

${}^{\rm A}_{\Lambda\Lambda}$Z	$\overline{B}^{\rm SM}_{\Lambda}({}^{\rm A-1}_{\ \ \Lambda}{\rm Z})$	$B^{\rm SM}_{\Lambda\Lambda}({}^{\rm A}_{\Lambda\Lambda}{\rm Z})$	$B^{\rm exp}_{\Lambda\Lambda}({}^{\rm A}_{\Lambda\Lambda}{\rm Z})$ [2]
${}^{11}_{\Lambda\Lambda}$Be	8.86 ± 0.10	18.39 ± 0.20	20.83 ± 1.27
${}^{12}_{\Lambda\Lambda}$Be	10.02 ± 0.05	20.71 ± 0.20	22.48 ± 1.21
${}^{13}_{\Lambda\Lambda}$B	11.27 ± 0.06	23.21 ± 0.21	23.3 ± 0.7

For the calculation of $B^{\rm SM}_{\Lambda\Lambda}({}^{11}_{\Lambda\Lambda}{\rm Be})$, since our SM fit maintains charge symmetry, we averaged statistically on $B^{\rm exp}_{\Lambda}({}^{10}_{\Lambda}{\rm Be}_{\rm g.s.})$ and $B^{\rm exp}_{\Lambda}({}^{10}_{\Lambda}{\rm B}_{\rm g.s.})$ [4] to get a SM input value $\overline{B}^{\rm SM}_{\Lambda}({}^{10}_{\Lambda}{\rm Be}) = (8.94 \pm 0.10)$ MeV. The SM prediction in Table I compares well with the CM prediction $B^{\rm CM}_{\Lambda\Lambda}({}^{11}_{\Lambda\Lambda}{\rm Be}) = 18.23$ MeV [1] in spite of the differing input. However, a meaningful comparison requires using identical interactions. For example, the induced nuclear spin-orbit interaction (parameter S_N), known to play a key role in p shell Λ hypernuclei [3], contributes close to 400 keV to $B^{\rm SM}_{\Lambda}({}^{10}_{\Lambda}{\rm Be}_{\rm g.s.})$ and twice as much to $B^{\rm SM}_{\Lambda\Lambda}({}^{11}_{\Lambda\Lambda}{\rm Be})$, but it is missing in the CM works [1, 5].

For the calculation of $B^{\rm SM}_{\Lambda\Lambda}({}^{12}_{\Lambda\Lambda}{\rm Be})$, we replaced the spin dependent and $\Lambda-\Sigma$ coupling contributions to $B^{\rm exp}_{\Lambda}({}^{11}_{\Lambda}{\rm B}_{\rm g.s.})$ [4] by those appropriate to ${}^{11}_{\Lambda}{\rm Be}_{\rm g.s.}$. For the calculation of $B^{\rm SM}_{\Lambda\Lambda}({}^{13}_{\Lambda\Lambda}{\rm B})$, since the value of $B^{\rm exp}_{\Lambda}({}^{12}_{\Lambda}{\rm C}_{\rm g.s.})$ is controversial, we used $B^{\rm exp}_{\Lambda}({}^{12}_{\Lambda}{\rm B}_{\rm g.s.})$ [4] plus a 161 keV $(1^-_{\rm g.s.}, 2^-_{\rm exc})$ doublet splitting from ${}^{12}_{\Lambda}$C [6].

The excellent agreement between $B^{\rm SM}_{\Lambda\Lambda}({}^{13}_{\Lambda\Lambda}{\rm B})$ and $B^{\rm exp}_{\Lambda\Lambda}({}^{13}_{\Lambda\Lambda}{\rm B})$ provides a consistency check on the SM estimates $B^{\rm SM}_{\Lambda\Lambda}({}^{11,12}_{\ \ \Lambda\Lambda}{\rm Be})$ listed in Table I. Comparing these estimates with the corresponding $B^{\rm exp}_{\Lambda\Lambda}$ options listed in the table, we conclude that a ${}^{12}_{\Lambda\Lambda}$Be assignment to the HIDA event is no more likely than a ${}^{11}_{\Lambda\Lambda}$Be assignment.

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